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# Offshore wind resource estimation for wind energy

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*Abstract* – Satellite remote sensing from active and passive microwave instruments is used to estimate the offshore wind resource in the Northern European Seas in the EU-Norsewind project. The satellite data include 8 years of Envisat ASAR, 10 years of QuikSCAT, and 23 years of SSM/I. The satellite observations are compared to selected offshore meteorological masts in the Baltic Sea and North Sea. The overall aim of the Norsewind project is a state-of-the-art wind atlas at 100 m height. The satellite winds are all valid at 10 m above sea level. Extrapolation to higher heights is a challenge. Mesoscale modeling of the winds at hub height will be compared to data from wind lidars observing at 100 m above sea level. Plans are also to compare mesoscale model results and satellite-based estimates of the offshore wind resource.

## I. INTRODUCTION

Satellite remote sensing offer several options on mapping of ocean winds. Satellite-based winds are used in oceanography and forecasting. Recently offshore wind energy resource mapping has taken advantage of satellite remote sensing data. In the project EU-Norsewind satellite remote sensing is used in combination with ground-based wind lidars and meteorological mast data(1). The collected data are used for either comparison to atmospheric model results or as input to the meteorological modeling. Satellite ocean wind maps are valid at 10 m above sea level. Offshore wind turbines operate at around 100 m. Therefore the vertical extrapolation of winds – the wind profile- is important to assess the wind resource.

## RESULTS

### Passive microwave

The longest series of satellite ocean winds are from the passive microwave radiometer, SSM/I. Examples of resource mapping using SSM/I in the North Sea and Baltic Sea are presented in (2; 3). The series encompass 23 years of data. Some have been compared to the FINO-1 meteorological station <http://www.fino-offshore.de/> in the North Sea. The calculation of the Weibull scale and shape parameters (4) has been done using SSM/I and comparing to the FINO-1 meteorological data. It appears that the distributions are similar, see Fig. 1.

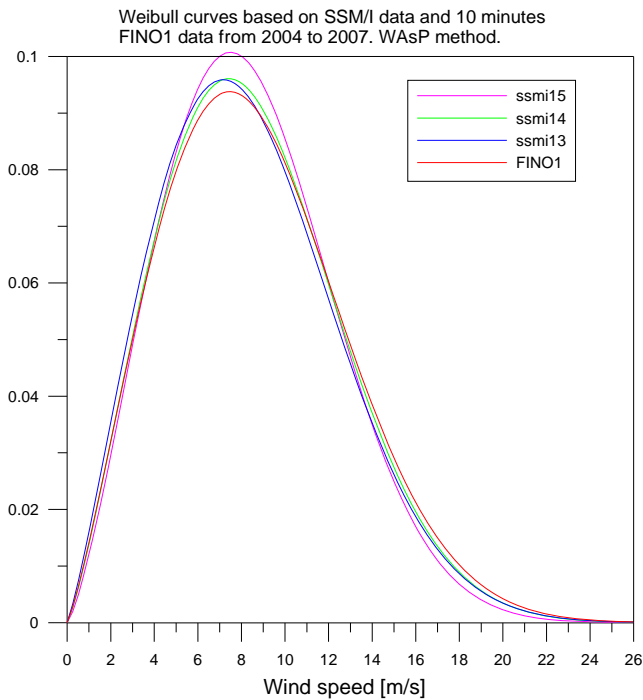


Fig. 1. Weibull curves calculated from SSM/I satellite observations from F-13, F-14 and F-15 and from FINO-1 meteorological data.

The variations at longer timescale, annual and monthly, are also quantified. For the inter-annual variability it is found that the actual power production of the wind farms in Denmark vary approximately with the variation of the SSM/I-based wind-index (2). At Dogger Banke in the North Sea where the largest offshore wind farm cluster is planned in the UK Round 3 is investigated from SSM/I. The wind speed variation at the hourly timescale is not very large far out in the North Sea at Dogger Banke and the inter-annual variability is moderate (3). SSM/I only map ocean winds rather far from the coastline.

### Scatterometer

Scatterometers in space also have a long history. Several scatterometers have been and are now flown on-board satellite platforms. Currently the ASCAT is the operational scatterometer for ocean wind vector mapping used in operational forecasting <http://www.knmi.nl/scatterometer/>. Furthermore, the new coastal ocean wind mapping product allow improved

mapping at shorter distance to the coast using ASCAT as the basic input to this product.

The QuikSCAT ocean wind products include a 10-year time series. For wind resource mapping the particular advantage is that wind vectors are available. The twice-daily observational pattern allows the morning versus evening passes to be compared. This reveal diurnal wind variations over the ocean. Fig. 2 shows an example from the Northern European Seas.

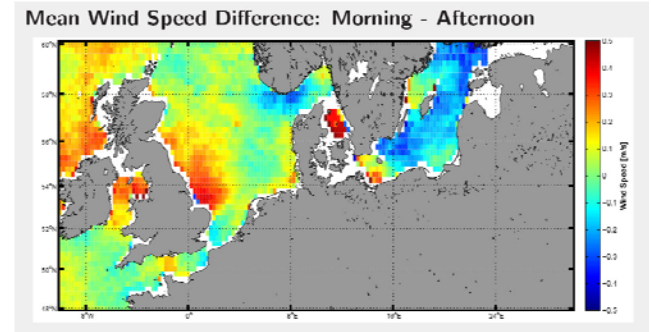


Fig. 2. Mean wind speed difference observed from 10-years of QuikSCAT ocean wind maps from REMSS.

The variation in diurnal wind speed from the morning passes minus the afternoon passes show up to 0.5 m/s near the UK whereas the difference is down to -0.5 m/s at some locations in the Baltic Sea. The mean wind speed in the area is shown in Fig. 3. The variation is from around 6.5 m/s to 9.5 m/s in the area.

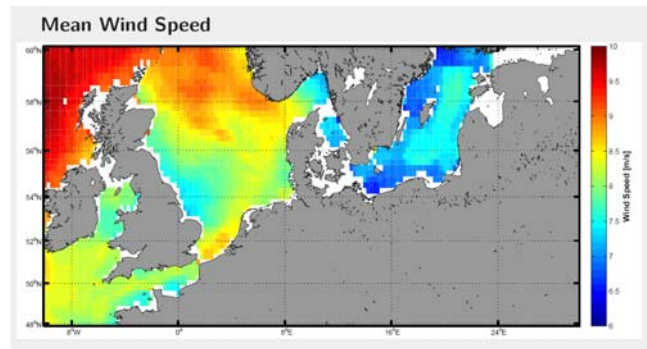


Fig. 3. Mean wind speed observed from 10-years of QuikSCAT ocean wind maps from REMSS.

### Synthetic Aperture Radar (SAR)

SAR ocean wind mapping has the advantage of higher spatial resolution compared to passive microwave and scatterometers. Thereby ocean wind mapping is possible at much shorter distances from the coastline. Background on ocean wind mapping from satellite SAR is provide in (5; 6).

In the Baltic Sea the SAR-based ocean wind mapping has been compared to the FINO-2 meteorological data <http://212.201.38.20/fino2/>. The mast is located approximately 38 km from land between Germany and Sweden at the position 13.154167 E, 55.006944 N.

A map of satellite ocean wind from SAR, from the European Space Agency (ESA) satellite Envisat is shown. The winds are retrieved using the CMOD5 (7) and with input of wind direction from the NOGAPS model in the

ANSWRS system (8) from Johns Hopkins University, Applied Physics Laboratory. The map in Fig. 4 covers the southwestern part of the Baltic Sea. The winds are coming from the east with up to 15 m/s wind speed and down to 5 m/s in the Danish interior seas. Lee effects of islands and other land areas are clear.

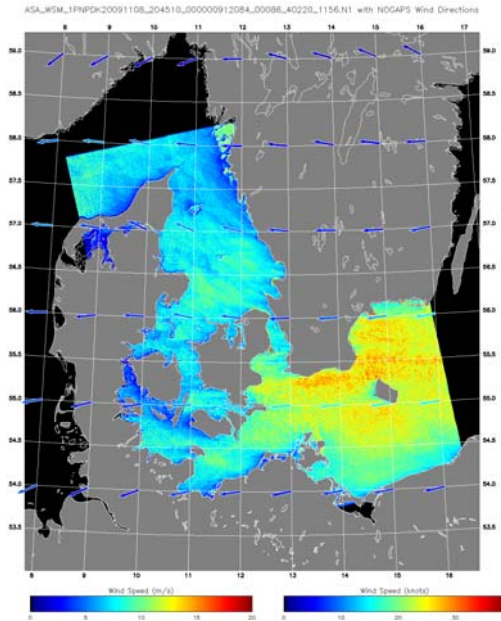


Fig. 4. Satellite SAR ocean wind map from Envisat ASAR Wide Swath Mode shows part of the Baltic Sea and interior Danish Seas. The image is from 8 November 2009 at 20.45 UTC.

178 SAR wind maps based on Envisat ASAR Wide Swath Mode images collected from December 2007 to September 2009 are collocated with hourly averages centered near the satellite observational time from the FINO-2 mast. The average wind speed from the meteorological mast is 8.16 m/s.

Two pixel-averaging methods in the SAR wind maps are tested. One is the footprint function for area-averaging following Gash (9), the other is a simplified ellipse shape following (10). The footprint of Gash has a physical basis, and the averaging of pixels follows the probability density function upwind of the location of interest (here set as the 90% limit). The simple ellipse on the other hand averages all pixels within the ellipse with equal weight (according to the size of area).

The result on average wind speed from the Gash footprint is 8.19 m/s and from the ellipse-footprint 8.11 m/s.

Linear regression results between the two data sets are also calculated. The result is  $y = 1.0386x - 0.2839$  with  $R^2 = 0.7729$  for the Gash footprint and  $y = 1.0278x - 0.3198$  with  $R^2 = 0.7351$  for the ellipse footprint. Thus the best result is found using the Gash footprint for the comparison at the FINO-2 mast using 178 collocated pairs. Scatterplots of data are shown in Fig. 5.

The lowest level of the FINO-2 mast is at 32 m above sea level. The SAR-based ocean winds are valid at 10 m above sea level. Thus before comparing the two data sets, the FINO-2 meteorological data are extrapolated down to

10 m. This was done using the neutral logarithmic profile and the roughness of Charnock with the constant set at 0.0144 following (11).

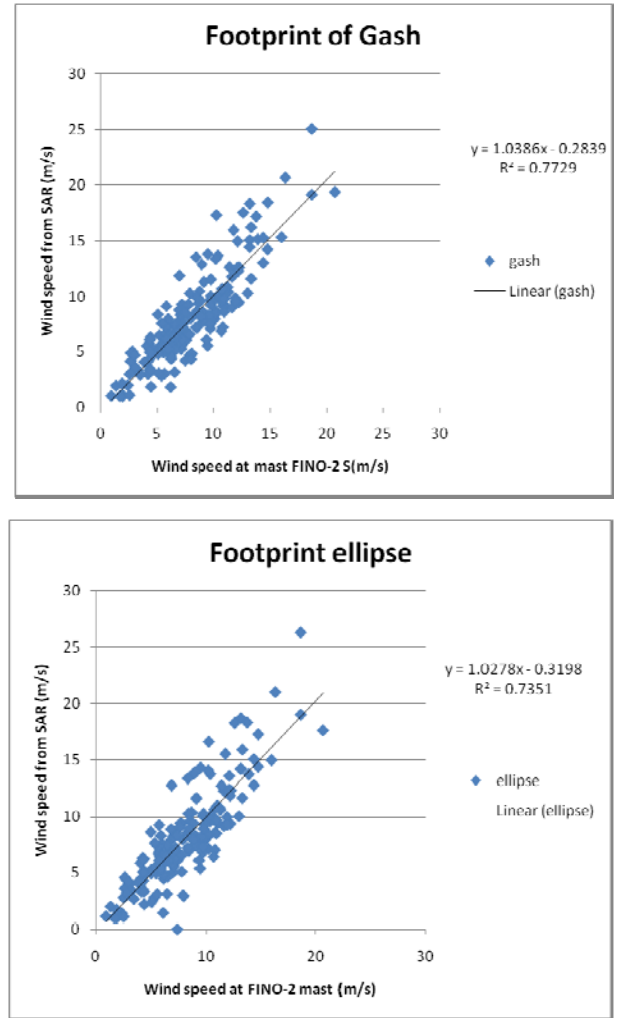


Fig 5. Comparison of wind speed observed at FINO-2 meteorological mast and from satellite SAR using 178 collocated Envisat images. Upper panel shows linear regression results using the Gash footprint for averaging in the SAR wind maps, lower panel similar for an ellipse footprint averaging.

The Weibull scale and shape parameters are calculated using all available SAR wind maps, i.e. 409 at the FINO-2 location. The images are collected from 2003 to 2010 from Envisat ASAR. The Weibull scale parameter is found to be 9.21 m/s (uncertainty 0.25 m/s) and the shape parameter 1.93 (uncertainty 0.07). This result is found using the fitting function of the maximum likelihood estimator. Using the same data set and the WAsP fitting function the result is Weibull scale 9.03 m/s (uncertainty 0.26 m/s) and Weibull shape 1.84 (uncertainty 0.08). Using all meteorological observations from the mast, extrapolated to 10 m as described above and using the WAsP fitting method gives Weibull scale of 8.49 m/s and Weibull shape of 2.31.

The observations from the mast are from a shorter period 1 year 9 months but sampled every 10 minutes,

whereas the satellite observations are from 7 years but sampled very infrequently. Each satellite wind map represent around 1-hour time slot, though taken within 15 seconds. The natural variations in wind speed during seasons and year introduce uncertainty to wind resource estimates.

Results in the North Sea show good comparison between three meteorological masts: Horns Rev, FINO-1 and Høvsøre coastal masts, comparing SAR-based wind resource statistics and meteorological observations (12; 13).

The future aim is to also compare the results to mesoscale model results in the North Sea and the Baltic Sea.

## CONCLUSION

Satellite remote sensing of ocean winds is readily available for the analysis. The challenges are to assess the difference in winds at 10 m above sea level and the winds at higher heights, the height of operation wind turbines, and to fit the probability functions to the observations. The EU-Norsewind project aims to quantify the differences through atmospheric modeling and comparison to observations. The work is in progress. The preliminary results indicate that satellite winds compare well to individual meteorological observations, and that the fitting method chosen for wind resource calculation can change the result.

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